SEISMIC BEHAVIOR SUBJECTED TO GROUND MOTION AND FAULT DISPLACEMENT OF HALF-THROUGH STEEL ARCH BRIDGE

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ABSTRACT

This paper presents the seismic behavior of the dynamic response analyses of a half-through steel arch bridge subjected to earthquake ground motion and fault displacement. Both the 1999 Taiwan Jiji Earthquake wave and fault displacement wave obtained from the time integral of the acceleration response wave were applied and the response behavior was investigated.

The dynamic response analyses were carried out using earthquake ground motion in transversal and longitudinal directions together with fault displacement in vertical direction or transversal direction, in order to investigate the seismic behavior of the steel arch bridge model. The analytical models and time histories analysis are simulated by 3D model of ABAQUS software.

According to the analytical results, the response behavior from both cases in transversal and longitudinal under acceleration shows a slightly different shape. It was also found that the plastic members were clustered near the intersections of arch ribs and stiffened girders.

Keywords: Seismic behavior, ground motion, fault displacement, half-through steel arch bridge.

1. INTRODUCTION

It is still necessary to establish a method concerning the effect of fault displacement to check the seismic performance developed from nonlinear dynamic analysis for arch bridges design. Furthermore, it is important to construct steel arch bridges possessing high seismic capacity at minimum cost. Half–through steel arch bridge is one of the arch bridges which reveal complicated behavior when subjected to ground motion or ground motion together with fault displacement. However, seismic performance and failure behavior for the half-through type arch bridge model have not been clarified yet and only few studies concerning nonlinear seismic analysis when subjected to fault displacement have been reported. This paper presents the seismic behavior of the dynamic response analyses of a half-through steel arch bridge subjected to earthquake ground motion and fault displacement.

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2. SEISMIC RESPONSE ANALYSIS

2.1. Theoretical arch model

The theoretical arch model studied herein is representative for actual half-through type arch bridges as shown in Figure 1, in which 11 vertical columns are hinged to arch ribs at both ends. The arch has a span length (*l*) of 106 m and the arch rise (*f*) is 22 m. The global axes of the arch ribs are also shown in Figure 1, where *b* and *L* represents the width of a stiffened girder and the deck span, respectively. The cross sectional profiles of vertical members and lateral members are rectangular and I-sections as shown in Figure 2.

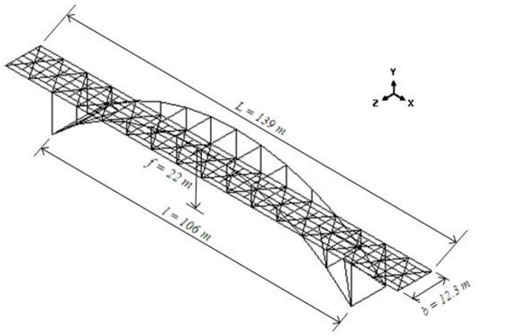
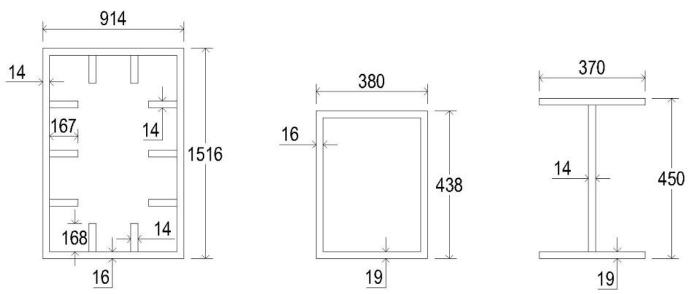


Figure 1: Theoretical arch model



a) Arch rib   b) Vertical column   c) Lateral member

Figure 2: Cross sectional profiles of members

The model was assumed to have no residual stresses and initial crookedness modes. Material properties of the model used in the numerical analyses were assumed to be SM490Y steel type (JIS) with the yield stress (σ_y) of 353 MPa and Young's modulus E was 206 GPa, respectively. The arch rise-to-span ratio (f/l) was taken to be 0.21 according to the condition of the actual arch bridges.

2.2. The Input seismic waves and fault displacement

The seismic wave which used in this analysis is shown in Figure 3. The fault displacement wave was obtained from the time integral of the acceleration response wave, that is, the ground motion simulated from 1999 Taiwan Jiji Earthquake wave. For the 1999 Taiwan Jiji Earthquake input wave, relative fault displacement measured after the earthquake was also concerned. There are three fault displacement waves are used in this analysis, which are TCU68EW2-3, TCU68EW2-5 and

TCU68EW2-6, as shown in Figure 4. The relative displacement curve for different two fault displacement waves and the maximum relative displacement wave is three meters, as shown in Figure 5. In dynamic response analysis, both the seismic waves and the fault displacement wave were input in order to simulate the movement at both ends of stiffened girder and at both arch springing.

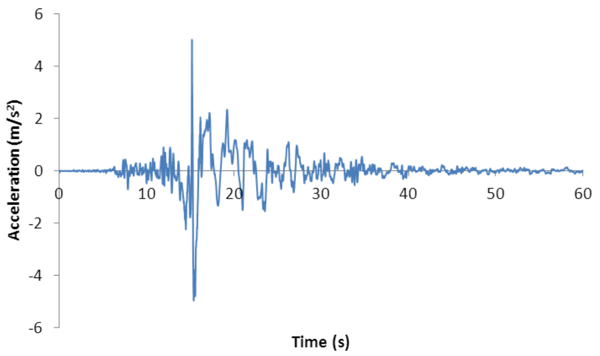


Figure 3: 1999 Jiji earthquake input acceleration wave

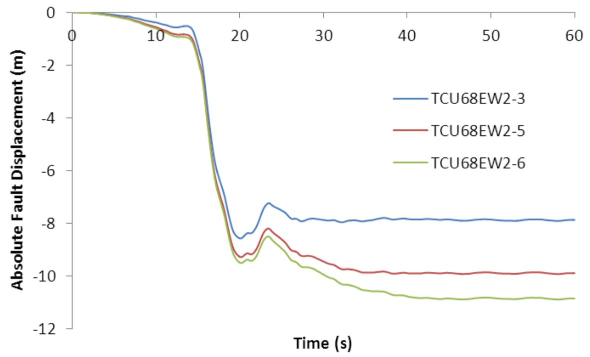


Figure 4: 1999 Jiji earthquake input fault displacement

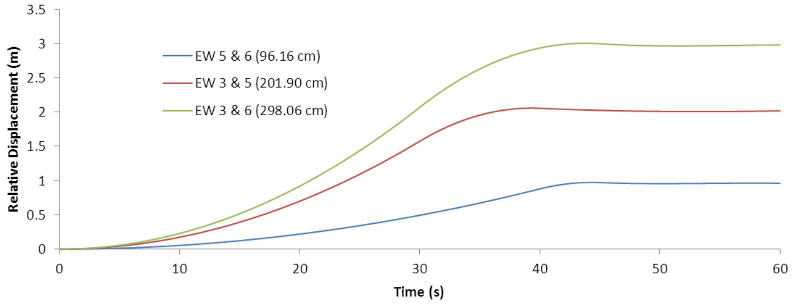


Figure 5: The relative displacement curve for different two fault displacement waves

2.3. Eigenvalue analysis

The eigenvalue analysis was carried out to investigate the effect of arch ribs and stiffened girders on the natural periods of the arch bridge model. In order to understand the fundamental dynamic characteristics, Table 1 presents the natural periods and the effective mass ratios of each predominant mode, from ABAQUS software. The maximum effective mass ratios obtained in X, Y and Z directions imply the order of the dominant natural period.

2.4. Damping matrix and numerical analysis

Numerical analyses were conducted using the Newmark-β method (β = 0.25) where the equations of motion were integrated with respect to time taking into account geometrical non-linearity. A constant time step of 0.01 sec and a damping model (Rayleigh type) calibrated to the initial stiffness and mass were utilized. The seismic response analysis with ground acceleration input and a constant dead load was performed using the nonlinear FEM program ABAQUS, which is capable of taking account geometric and material non-linearity.

Table 1: Results of eigenvalue analysis

Order of period	Natural Frequency (Hz)	Natural Periods (sec)	Effective mass ratio (%)		
			X	*Y*	*Z*
1	1.0341	0.9670	74	0	0
2	1.9767	0.5059	0	0	75
3	2.6452	0.3780	0	0	0
4	2.6452	0.3780	0	0	0
5	3.3823	0.2957	0	0	0
6	3.7199	0.2688	26	0	0
7	4.1054	0.2436	0	0	25
8	4.1988	0.2382	0	100	0
9	5.0428	0.1983	0	0	0
10	5.2847	0.1892	0	0	0

3. RESPONSE BEHAVIOR OF FAULT DISPLACEMENT

The dynamic analysis of the arch bridge model is conducted in direct integration analysis. In this analysis, the seismic waves were input in longitudinal and transverse direction, by ABAQUS software. The cases that will be discussed in this paper are described in Table 2.

Table 2: Cases in the analysis

Case	*Fault displacement direction*	*Acceleration direction*
I-a	Y	X
I-b	Y	Z
II-a	Z	X
II-b	Z	Y

By using the acceleration data for longitudinal direction and fault displacement of Jiji Earthquake, with the damping ratio (h) = 0.03, the longitudinal displacement (X-direction) and in-plane displacement (Y-direction) have been checked at the arch crown, in the case of applying fault displacement in Y-direction (Case I). Figure 6 and Figure 7 show the displacement response obtained from the dynamic analysis in X-direction (in acceleration direction) and in Y-direction (in fault displacement direction) in the Case I-a.

The dynamic analysis was also carried out in transversal direction in the same procedure for the Case I-b. The transversal displacement (Z-direction) and in-plane displacement (Y-direction) have been checked at the arch crown. Figure 8 and Figure 9 show the displacement response obtained from the dynamic analysis in Z-direction (in acceleration direction) and Y-direction (in fault displacement direction) which is the problem in Case I-b.

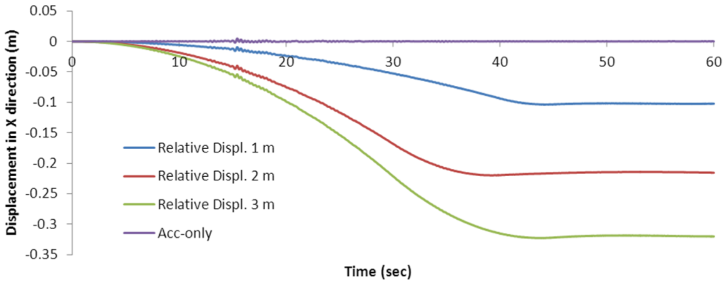


Figure 6: Displacement-time history response in X-direction (in acceleration direction) in Case I-a

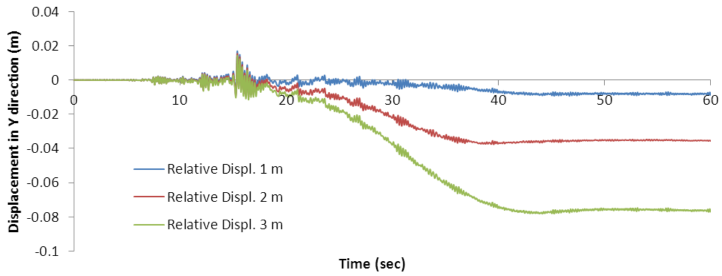


Figure 7: Displacement-time history response in Y-direction (in fault displacement direction) in Case I-a

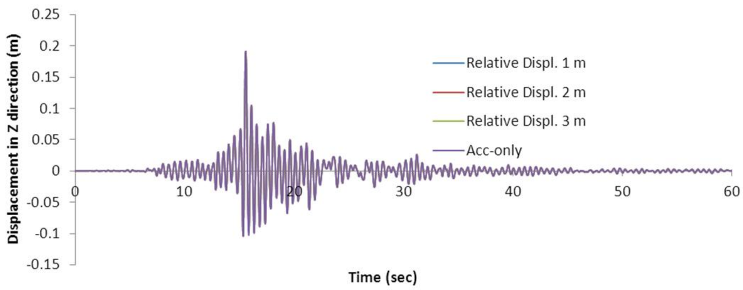


Figure 8: Displacement-time history response in Z-direction (in acceleration direction) in Case I-b

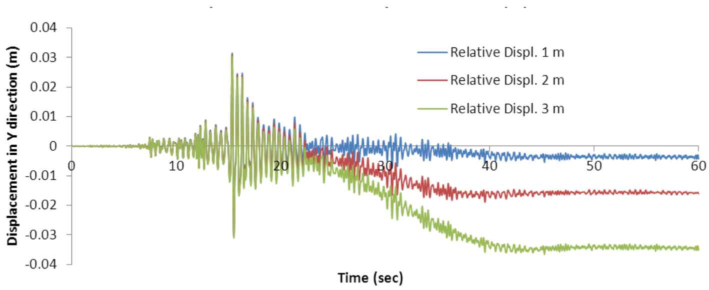


Figure 9: Displacement-time history response in Y-direction (in fault displacement direction) in Case I-b

In the case of applying fault displacement in Z-direction (Case II), with acceleration in longitudinal direction (X-direction) and in-plane direction (Y-direction), the results of the analysis can be seen in Figure 10 to Figure 13.

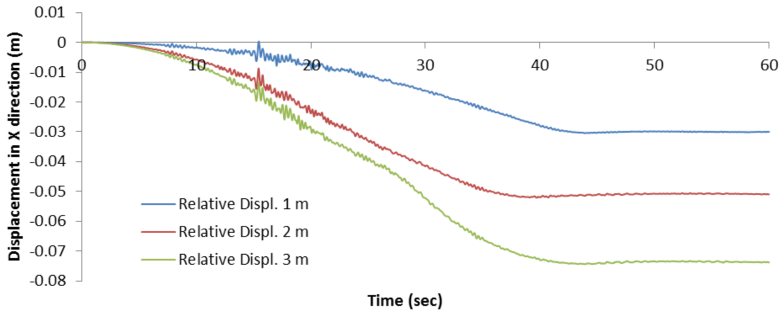


Figure 10: Displacement-time history response in X-direction (in acceleration direction) in Case II-a

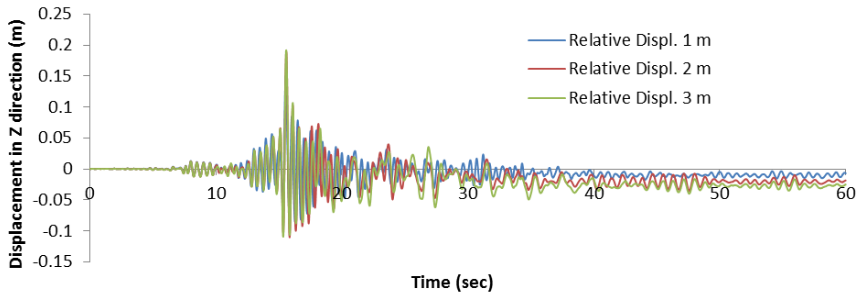


Figure 11: Displacement-time history response in Z-direction (in fault displacement direction) in Case II-a

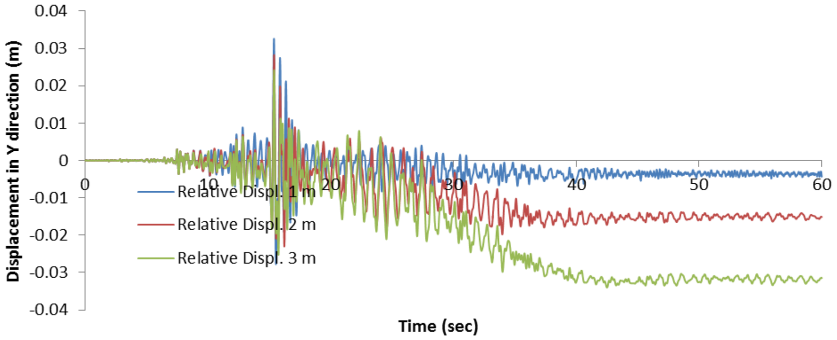


Figure 12: Displacement-time history response in Y-direction (in acceleration direction) in Case II-b

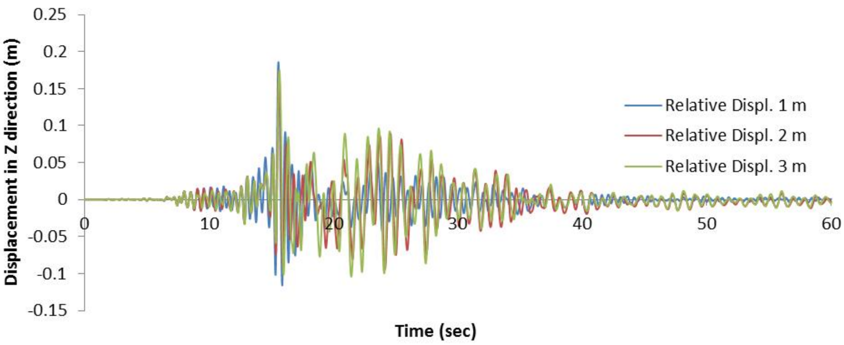
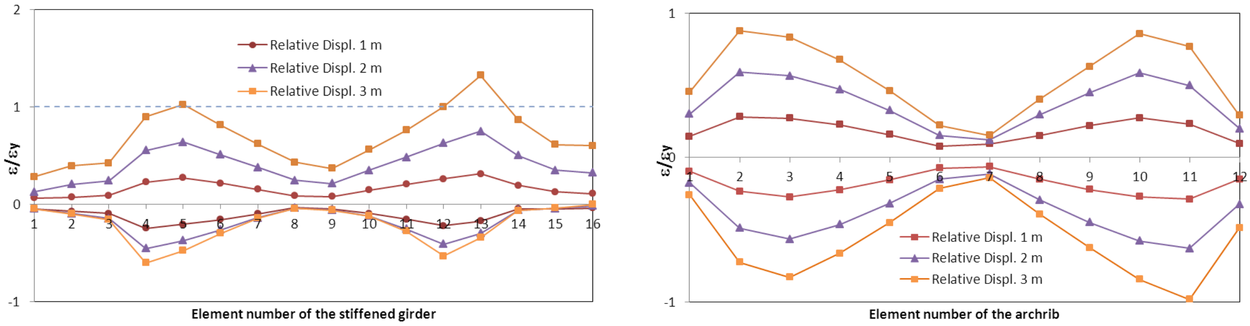


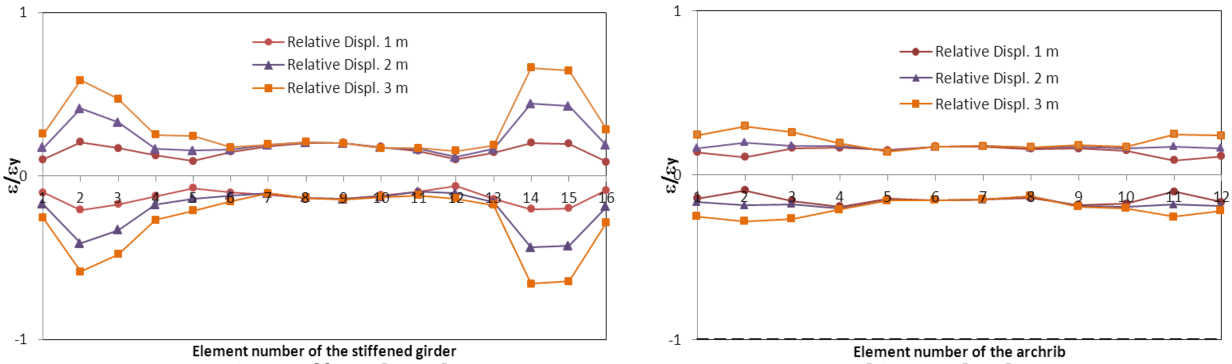
Figure 13: Displacement-time history response in Z-direction (in fault displacement direction) in Case II-b

Furthermore, it is also recognized that in this analysis, some of the stiffened girders reach yield for both loading in longitudinal direction and transversal direction. It is shown in Figure 14 for the acceleration in longitudinal (X) direction and Figure 15 for the acceleration in transversal (Y) direction for the maximum and minimum plastic ratios $\varepsilon/\varepsilon_y$ of strains responses in the stiffened girder and the arch rib along the bridge model. This behavior is caused by the magnitude of the acceleration recorded from the earthquake.



b) Stiffened girder a) Arch rib

Figure 14: Maximum and minimum plastic ratios $\varepsilon/\varepsilon_y$ of strains responses in the a) stiffened girder b) arch rib (for acceleration in longitudinal direction)



a) Stiffened girder b) Arch rib

Figure 15: Maximum and minimum plastic ratios $\varepsilon/\varepsilon_y$ of strains responses in the a) stiffened girder b) arch rib (for acceleration in transversal direction)

According to the analytical results, it was found that the plastic members were clustered near the intersections of arch ribs and stiffened girders. And this is caused by the large deformation at these intersection zones. From the figures, it is shown also that in both stiffened girder and the arch rib in acceleration in longitudinal direction resulted larger strain response comparing with the result from the strain in the case of acceleration is in transversal direction. This is the influence of the structure stiffness in both directions.

4. CONCLUSIONS

The seismic behavior of a half-through steel arch bridge subjected to ground motions in longitudinal and transversal directions together with fault displacement in transversal and in-plane direction were investigated by dynamic response analysis. The conclusions of this study are summarized as the following.

1) The effect of the fault displacement wave direction on the damage of the half-through steel arch bridge model is dominant.
2) The results obtained from dynamic analysis indicate that the plastic members are clustered near the joints of the arch ribs and the stiffened girders for longitudinal and transversal directions. This is caused by the large deformation at this intersection zones.
3) The maximum displacements taken from displacement response in longitudinal direction occur under earthquake wave in longitudinal direction. And the arch bridge model is judged to damage under the three meters relative displacement in this earthquake wave because the maximum stress in members reaches their yield stresses.

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